

PROGRESSIVE TOOL WEAR IN MACHINING BIOMEDICAL ALLOY USING UNCOATED AND TITANIUM DIBORIDE COATED TUNGSTEN CARBIDE TOOLS

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Di dalam industri pemrosesan bahan aloi kobalt kromium (CoCr), logam keras terdiri daripada pecahan tinggi bijian tungsten karbida (WC) atau karbon boron nitrida (CBN) yang tertanam dalam matriks pengikat kobalt (Co) yang agak lembut dan kukuh digunakan secara meluas untuk aplikasi pemotongan dan daya tahan haus. Walaupun meraih populariti sebagai bahan termaju di dalam pelbagai bidang seperti aeroangkasa dan automotif; kerana sifat unggulnya seperti nisbah kekuatan-berat, dan dalam bidang bioperubatan kerana ketahanan kakisan dan keserasian biologi yang tinggi, namun, pemesinan aloi ini telah terbukti sukar untuk dipotong. Faktor utama yang mengurangkan daya pemesinan CoCr aloi adalah kerana sifat afiniti kimia di antara kromium (Cr) dan Co pengikat di dalam tungsten karbida yang sangat kuat dimana menggalakkan kecenderungan untuk mengimpal pada alat pemotong semasa pemesinan, seterusnya mengakibatkan serpihan dan kegagalan pramatang alat. Kajian ini dijalankan untuk menyiasat progresif kehausan alat dalam pemesinan aloi kobalt kromium dan menilai prestasi pemesinan merangkumi jangka hayat alat, mekanisme kehausan, suhu pemotongan alat dan kekasaran permukaan bahan kerja dalam keadaan pemesinan kering menggunakan alat tidak bersalut dan disaluti *titanium diborid* (TiB_2). Sebelum ujian dimulakan, ciri-ciri bahan kerja dinilai menggunakan ujian fizikal dan mekanikal. Parameter pemotongan ditetapkan dengan kelajuan pemotongan (V_c): 60 m / min, kadar suapan (f): 0.1 mm/rev, dan kedalaman potongan (a_p): 0.25 mm sepanjang ujian pemotongan. Jangka hayat ditentukan berdasarkan piawai ISO3685: 1993. Mekanisme kehausan, suhu alat dan kekasaran permukaan diukur menggunakan mikroskopi elektron pengimbasan, termogandingan jenis K dan peranti Marsurf-PS1. Hasil pencirian alat pemotong menunjukkan bahawa lapisan tunggal TiB_2 menawarkan kekerasan yang tinggi yang boleh meningkatkan ketahanan rintangan pada alat WC terhadap kegagalan pramatang. Daripada penilaian prestasi pemesinan alat bersalut TiB_2 terhadap alat tidak bersalut, menunjukkan bahawa jangka hayat pemotongan untuk kedua-dua jenis alat dapat dicapai lebih daripada lima minit. Penyiasatan lanjut mengenai kadar kehausan untuk alat walaubagaimanapun menunjukkan bahawa alat tidak bersalut mengalami kadar haus yang lebih tinggi sebanyak 13.7 % dibandingkan alat bersalut TiB_2 . Fenomena kehausan alat menjejaskan kekasaran permukaan dan mekanisme kehausan dimana purata kekasaran permukaan alat bersalut adalah 0.9 μm dan tidak bersalut adalah 1.4 μm . Mekanisme kehausan untuk kedua-dua alat pemotong diperhatikan sama iaitu lekatan dan lelasan. Walau bagaimanapun, berdasarkan analisis elemen sinaran x-ray (EDX), lapisan salutan pada alat pemotong dapat mengurangkan pengimpalan elemen bahan yang menyebabkan mekanisme haus lekatan pada alat pemotong. Kesimpulannya, peningkatan prestasi yang ditunjukkan oleh alat pemotong karbida bersalut TiB_2 di dalam pemesinan kering untuk aloi kobalt kromium sebanyak 1.38 % perbezaan kehausan alat. Ini telah membuka langkah penting untuk proses pembuatan tinggi yang mampan dalam industri aeroangkasa, automotif dan perubatan. Penyelidikan analisis terhadap pengaruh parameter pada pemesinan aloi kobalt kromium adalah disyorkan untuk memperoleh kondisi pemotongan yang optimum untuk meningkatkan aspek ekonomi dan kualiti proses pemesinan bahan.

ABSTRACT

In the industry of cobalt chromium (CoCr) alloys processing, hard metals consist of high fraction of tungsten carbide (WC) or carbon boron nitride (CBN) grains embedded in a relatively soft and tough cobalt (Co) binder matrix are widely used for the cutting materials and wear resistant applications. Albeit gaining popularities as advanced materials in various aerospace, automotive and medical applications; owe to their superior properties such as good strength-to-weight ratio, and biomedical applications due to high corrosion resistance and biocompatibility, machinability of these alloys has been proven difficult to cut. Major factor reducing the machinability of CoCr alloys is the very strong chemical affinity between the Cr and Co binder in the tungsten carbide tool which encourages tendency of weldment of the work material to the cutting tool during machining, resulting notch, chipping and premature tool failure. This study was conducted to investigate the progressive tool wear in machining cobalt chromium alloys and evaluate the machining performance in terms of their tool life, wear mechanism, tool cutting temperature and surface roughness of the workpiece in dry machining using uncoated and titanium diboride (TiB_2) coated tools. To investigate the gradual generation of wear of the cutting tools, it is important prior cutting trials to evaluate the characteristics of the tool materials using physical (i.e. density and surface roughness of the tools with and without coating), and mechanical (i.e. micro hardness and heat distribution inside the tool bulk) tests. Then for the cutting trials cutting parameters of the CNC turning process were kept constant; i.e. cutting speed (V_c): 60 m/min, feed rate (f): 0.1 mm/rev, and depth of cut (a_p): 0.25 mm with original workpiece diameter 50 mm. The tool life was determined based on standard ISO3685:1993. The wear mechanism, wear generation, tool temperature and surface roughness were measured using scanning electron microscope, portable microscope, K-type thermocouple and Marsurf-PS1 device, respectively. The results of cutting tool characterisation indicate that the single layer TiB_2 offers high hardness which can intensify wear resistance of WC tool against premature tool failure. Assessing the machining performance of TiB_2 coated tool against uncoated tool, presented that tool life of over five minutes can be achieved with both tools. Further investigation on the rate of tool wear though showed that uncoated tool undergone higher wear rate of 13.7 % than TiB_2 coated tool. The phenomenon of tool wear affected surface roughness and wear mechanism as the average surface roughness of coated tool is 0.9 μm and uncoated is 1.4 μm . The same wear mechanism for both cutting tool were observed including adhesion and abrasion. However, based on the energy dispersive x-ray (EDX) elemental analysis, the coating of the cutting tool reduces the weldment of material element which causes adhesion wear mechanism on cutting tool. In conclusion, the improvement of machining performance exhibited by TiB_2 coated carbide cutting tool in dry machining of cobalt chromium alloy with 1.38 % percentage difference of flank wear. This has paved a significant step for sustainable manufacturing of high end applications in aerospace, automotive and medical industries. Analytical investigation into the effects of cutting parameters on the machinability of CoCr alloys is recommended to obtain optimum cutting condition for improving economical and quality aspects of machining.

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LIST OF SYMBOLS

a_p	Depth of cut
f	Feed rate
Ra	Surface roughness
t	Time
T	Temperature
V	Cutting speed
VB	Flank wear
ρ	Density

LIST OF ABBREVIATIONS

AlCrN	Aluminium Chromium Nitride
Al ₂ O ₃	Aluminium Oxide
B	Boride
BUE	Built-up-Edge
BUL	Built-up-Layer
C	Carbon
CBN	Cubic Boron Nitride
Cl	Chlorine
CNC	Computer Numerical Control
CoCr	Cobalt chromium
CoCrMo	Cobalt Chromium Molybdenum
CVD	Chemical Vapour Deposition
EDM	Electrical Discharge Machining
EDX	Energy Disperse X-ray
HSS	High Speed Steel
HRC	Rockwell C hardness
ISO	International Organization for Standardization
LBM	Laser Beam Machine
LN ₂	Liquid Nitrogen
MPa	Megapascal
MLQ	Minimum Quantity lubrication
N ₂	Nitrogen
PCD	Polycrystalline Diamond
PVD	Physical Vapour Deposition
SEM	Scanning Electron Microscope
SLM	Selective Laser Melting
SME	Small-to-Medium Enterprise
SS	Stainless steel
TiAlN	Titanium Aluminium Nitride
TiB ₂	Titanium Diboride
TiC	Titanium Carbide
TiCN	Titanium Carbo-Nitride
TiN	Titanium Nitride
WC	Tungsten Carbide

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